Update on NOAA CO_2 Retrievals: Validation and Future Directions

Eric Maddy, Chris Barnet, Mitch Goldberg, Xingpin Liu, Lihang Zhou and Walter Wolf.

NOAA/NESDIS/STAR

AIRS Science Team Meeting

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Outline

- Description of NOAA AIRS CO_2 retrieval methodologies
- How well can we do with a simple climatology?

$$\mathrm{CO}_2(t) = a_0 + a_1 * t$$

  - Development of error estimates.
  - Paper on averaging kernels (related to these error estimates) accepted (with revisions) to IEEE TGARS.
- Validation with full resolution data vs. NOAA ESRL/GMD Aircraft (2005)[1] and Global Gridded data vs. JAL Matsueda (August 2003 - 2006.)
- Comparison of AIRS and models – What new information can AIRS provide to modeling community?

[1] Submitted to JGR in review

NOAA AIRS CO_2 Retrievals

- Use AIRS Science Team Methodology.
    - Version 4.7.
        - before cloudy regression introduced.
        - NOAA O_3 regression on.
    - 70 channels (mostly 15 micron).
    - Derive CO_2 in 4 layers in troposphere, 1 stratospheric.
- Use Optimal Estimation w/ SVD
    - Runs within offline science code (consistent RTA/channel set).
    - Derive 6 - 10 CO_2 basis functions.
    - Runs very fast *No appreciable difference in run-time compared to AIRS Science Team methodology*
- Validation with full resolution data vs. NOAA ESRL/GMD Aircraft (2005) and JAL Matsueda between August 2003 - 2006 (only AIRS Science Team approach).

Each retrieval methodology has the ability to calculate averaging kernels and related diagnostics (d.o.f., etc.) and propagate error estimates.

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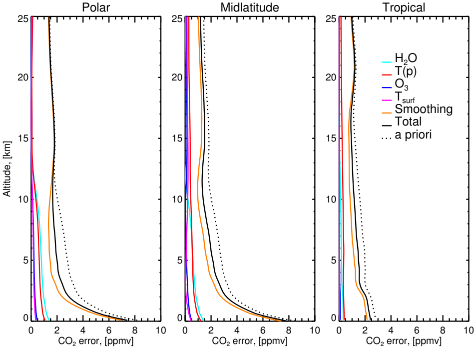
Improvement Over Simple Climatology

- Theoretical error analysis for our Version 5 Climatology



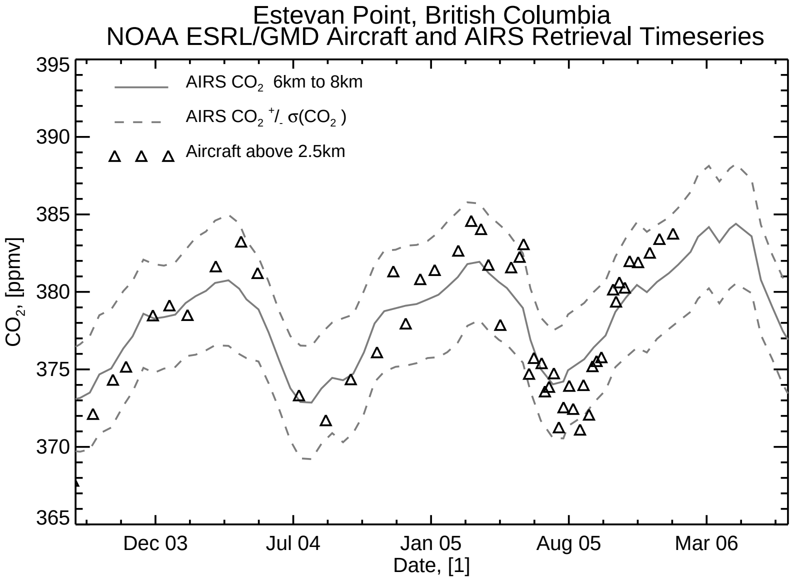
- Calculation uses *a priori* covariance calculated as the dif ference between ESRL aircraft and our simple Version 5 climatology.
- Ability to partition error sources and their effect on the retrieval. Effect minimized as we have assumed a *perfect* knowledge of the error covariation of intefering species (assumed *ad-hoc*: $S(z, z') = \sigma(z)\sigma(z') \cdot \exp(-|z - z'|/L)$).

ESRL/GMD Aircraft Validation Approach

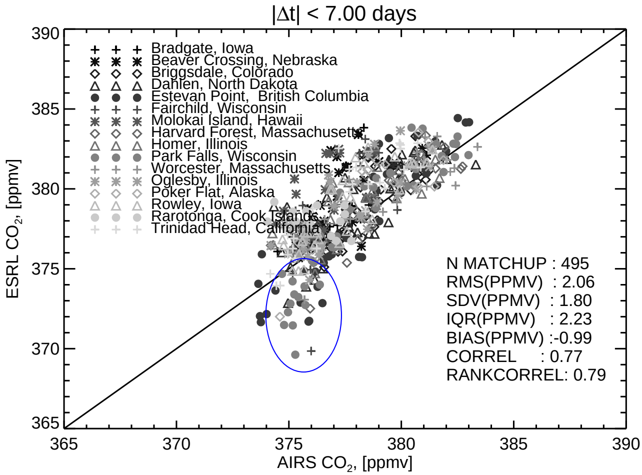
- Use full resolution AIRS retrievals (previously validated w/ 3°x 3°grids)
- Average AIRS CO_2 between 6-10 km (nominally where jacobian has maximum sensitivity).
- Use nominal jacobians (wrt. latitude) to weight ESRL aircraft.
  - Enables comparison of scalar measurements
  - Removes variability in lowest 2.5 km
- Average all retrievals within 200km with temporal matchup window between 1 day - 1 month.
- Profile statistics will also be shown. NOAA/ESRL CarbonTracker[2] model used to extend profiles above 8 km.

[2] http://www.cmdl.noaa.gov/ccgg/carbontracker

Example Comparison: Estevan Point, British Columbia



AIRS Science Team Algorithm vs. ESRL/GMD Aircraft



- Total magnitude of drawdown at LEF not captured possible over-regularization wrt. characteristic variability.

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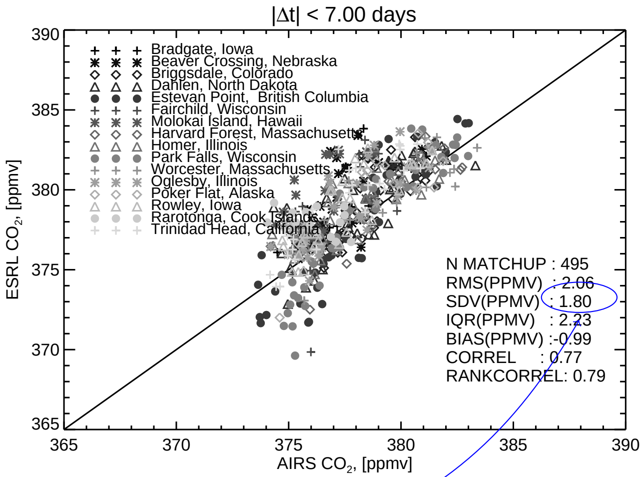
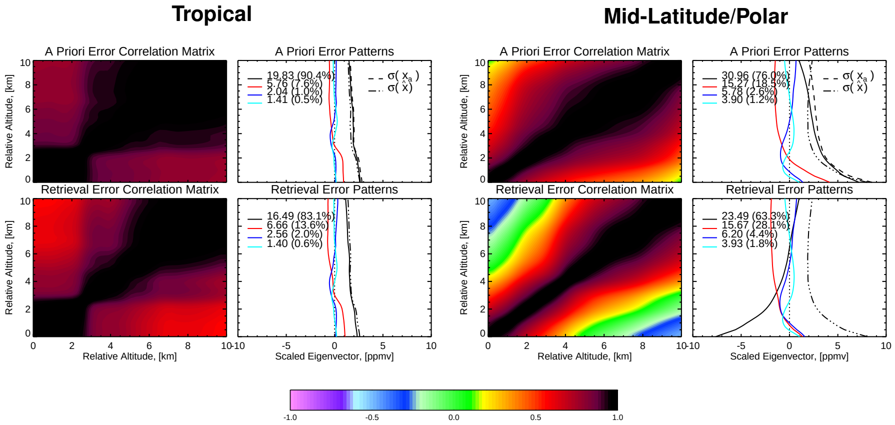


- 0.5% uncertainty from space!

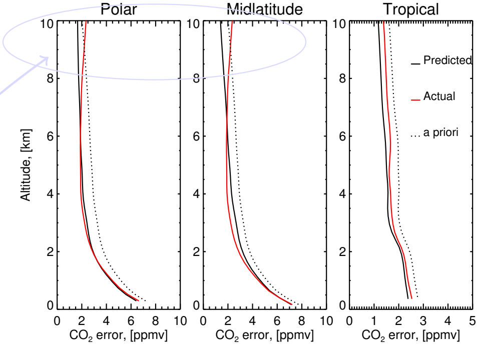
Calculated *a priori* and Retrieval Error Covariances



- Total variance of the retrieval is less than the *a priori* indicating a gain in information.
- First eigenfunction variance (and percent of total variance) of the retrieval is less than *a priori*.
- Retrieval tends to redistribute variance among higher order eigenfunctions, which are similar in shape to the *a priori*, indicating we have only 1 piece of information, albeit well constrained, in the vertical. Vertical resolution ≈6-8 km.

Validation of Error Propagation

- In general, predicted errors and actual errors compare very well.



- Largest discrepancy is above 8 km where the NOAA CarbonTracker model was used to extend the aircraft profiles.
- Uncertainties in the profile extension procedure, the model profiles, AIRS retrievals and/or error analysis are possible explanations to the disagreement.

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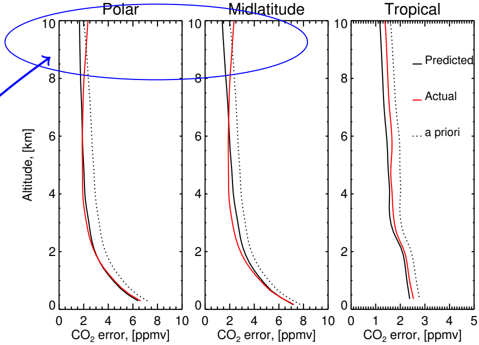

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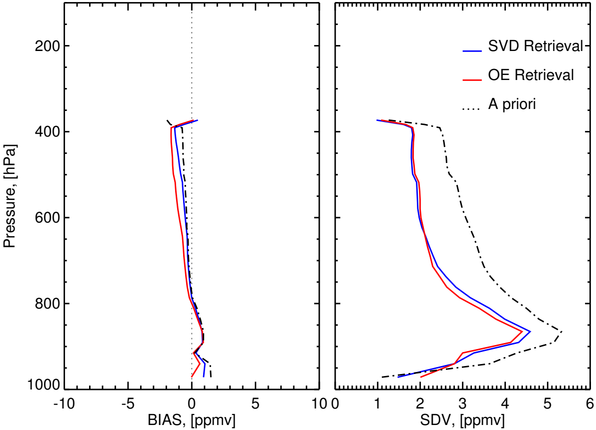
Comparison of OE and SVD approaches: independent validation

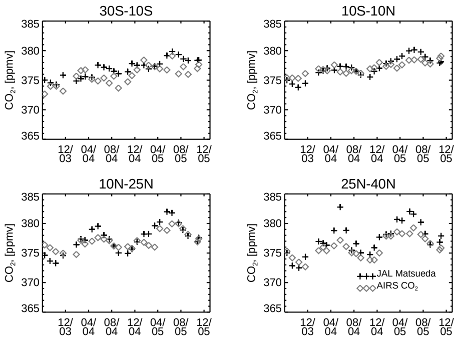


- Two retrievals with completely different methods of regularization yield almost the same results.

JAL Aircraft Validation Approach

- NOAA 3°x 3°gridded subset
- Average AIRS CO_2 between 6-10 km (nominally where jacobian has maximum sensitivity).
- Average all retrievals within 1000km with temporal matchup 1 month.
- Compare to monthly averaged JAL Matsueda over latitude range (27 months total between August 2003-2006).

AIRS Science Team Algorithm vs. JAL Matsueda



- SDVE $<$ 1.5 ppmv for all latitude ranges
- Variability in the accuracy wrt. latitude on the order of retrieval precision
  - related to sensitivity of jacobians to H_2O displacement.
  - zonal variability of information content.
- Averaged over all latitudes, AIRS retrievals compare very well: **-0.62 $\pm$ 0.87 ppmv**

Latitude Range	SDVE [ppmv]	BIAS [ppmv]
30S - 10S	1.32	-1.08
10S - 10N	1.04	-0.06
10N - 25N	1.45	-0.42
25N - 40N	1.45	-1.43
30S - 40N	0.87	-0.62

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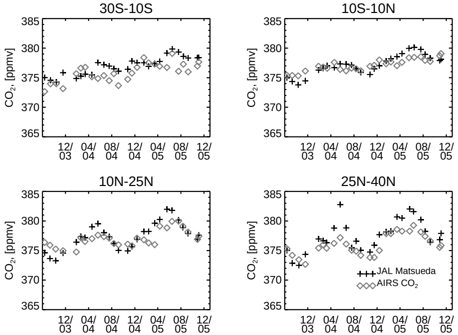

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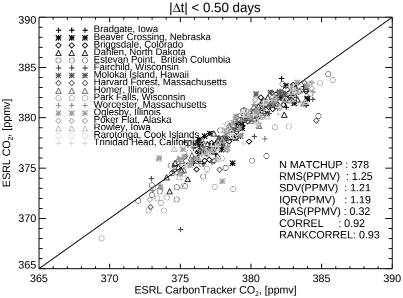
NOAA ESRL/GMD CarbonTracker vs ESRL/GMD Aircraft

- NOAA ESRL/GMD CarbonTracker weighted using AIRS jacobians.



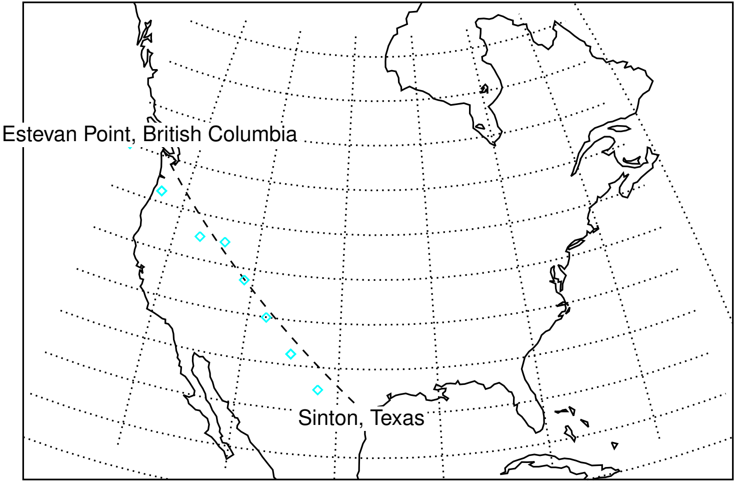
- 0.5 ppmv better precision than AIRS baseline, however CarbonTracker has been optimized for N. America.
- From our eigenvector analysis of our *a priori*, the 1^{st} eigenfunction, a total column perturbation, explains 80-90% of the variance.
- We would expect good agreement near ESRL aircraft sites because constraint of having surface / tower measurements in the assimilation.

Approach to Estimate AIRS Impact

- Determine scales of variability in CarbonTracker calculated as the gradient in a given direction over a defined time scale.
- Compare to see if AIRS captures the same sort of gradients.
- 3°x 3°grids used for comparison.

Thanks to Wouter Peters (NOAA ESRL) for suggesting using CarbonTracker for this approach.

ESRL/GMD CarbonTracker and AIRS Retrieval CO_2 Gradients



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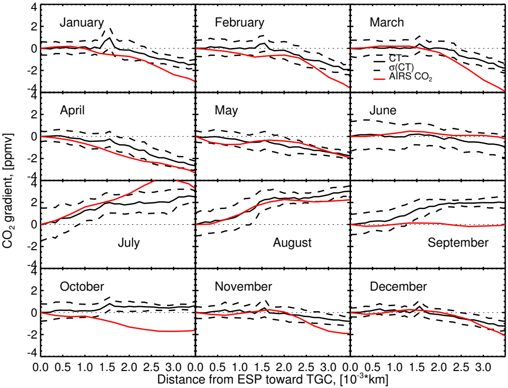

- 1-σ monthly variability of FT gradients shows that in general we need to resolve 1 ppmv signals (larger variability in summer months due to rectifier) on short timescales.
- Monthly averaged free tropospheric (FT) gradients are within our expected error budget in terms of matching seasonality and horizontal placement.

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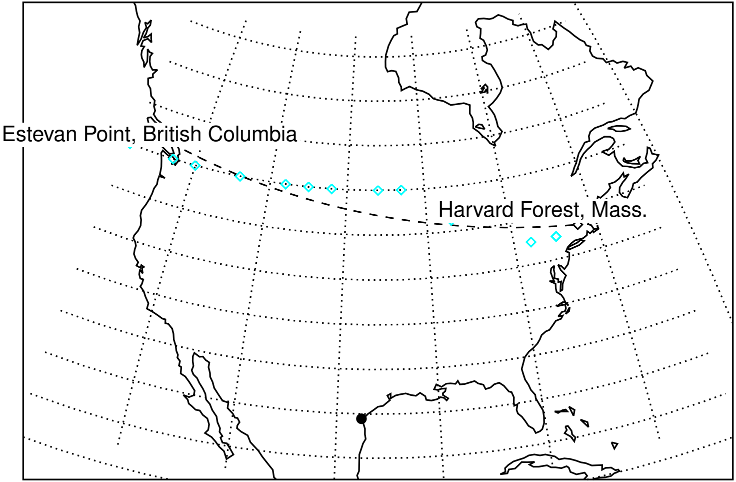

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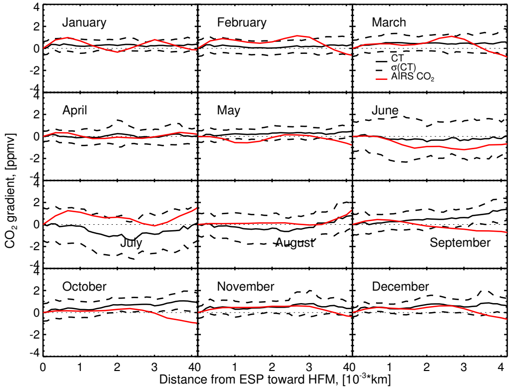


- CarbonTracker shows lack of FT gradient due to rapid advection/mixing of surface fluxes.
- East-to-west 1-σ variability largest in the summer months due to frontal passages and hence strong mixing (weekly differences in gradients $\approx \pm 3$ ppm).
- Considering retrieval error budget (wrt. aircraft) we may be able to resolve these features on weekly timescales; however, more study is required.

Summary

- Able to provide global retrievals of CO_2 on 1-2 weekly timescales at 1 - 2ppmv precision with a globally fixed *a priori*.
    - Modeling groups at NASA/GSFC, UC/Berkeley, and University of Leicester, UK have just begun looking at the product.
- Theoretical error estimates enable quick calculation of the AIRS data impact. These require accurate large scale correlations in *a priori* due to the broad width of the kernel functions.
- Require more high altitude profile validation data to gain confidence in product error correlation.

Summary: Future Plans

- True test of product skill is the ability to discern CO_2 gradients.
- Model gradients W-E are generally small due to rapid advection of surface fluxes – we may be able to capture weekly differences.
- As expected N-S gradients are larger with monthly variability on the order of our precision.
- Monthly comparisons to CarbonTracker show similar features; more analysis required
  1. Determine our ability to match gradients over shorter timescales.
  2. Retest AIRS in regions poorly constrained. Model/retrieval comparisons underway for gradient appropriateness.
  3. Understand (inter)product error correlations $f(\text{time,space})$ that introduce anomalous gradients in AIRS CO_2.

Theoretical Gain Using a CarbonTracker *a priori*

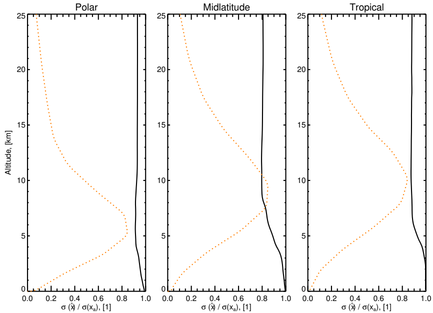
- Use error propagation to estimate gain in information content by adding AIRS CO_2 sensitive measurements initially with CarbonTracker errors, $\mathbf{S}_a^{\text{CTracker}}$.

$$\begin{aligned}\hat{\mathbf{S}} &= (\mathbf{A}-\mathbf{I})\mathbf{S}_a^{\text{CTracker}}(\mathbf{A}-\mathbf{I})^T \\ &\quad +\mathbf{D}\mathbf{K_b}\mathbf{S_b}(\mathbf{D}\mathbf{K_b})^T \\ &\quad +\ldots\end{aligned}$$

- We plot the error reduction defined as:

$$\text{diag}(\hat{\mathbf{S}})/\text{diag}(\mathbf{S}_a^{\text{CTracker}})$$

- Improvement outside of region where Jacobian (dotted line) is sensitive is largely due to error correlation assumed in $\mathbf{S}_a^{\text{CTracker}}$.



Improvement somewhat marginal; however, CarbonTracker is highly constrained by surface measurements hence $\mathbf{S}_a^{\text{CTracker}}$ is small.